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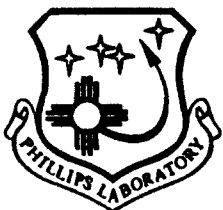
**ADVANCED MATERIALS FOR TURBOMACHINERY
TECHNICAL MEMO #2
ADVANCED MATERIALS COMPATIBILITY WITH
STORABLE PROPELLANTS
(MONOMETHYL HYDRAZINE AND NITROGEN
TETROXIDE)**

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October 1991



Final Report

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FOREWORD

This final report was submitted on completion of this phase of JON: 305800T2 by the OLAC PL/RCC Branch, at the Phillips Laboratory (AFSC), Edwards AFB CA 93523-5000. OLAC PL Project Manager was Erin B. Durham, Capt., USAF.

This report has been reviewed and is approved for release and distribution in accordance with the distribution statement on the cover and on the SF Form 298.

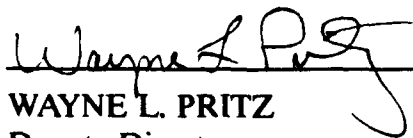


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13. ABSTRACT (Maximum 200 words) The Advanced Materials for Turbomachinery (AMT) program is tasked with determining which advanced materials currently on the market are the most suitable for applications to turbopumps. Initial work involves pumps carrying storable propellants (monomethyl hydrazine [MMH] and nitrogen tetroxide [NTO]), and the first tests to be completed are compatibility tests of Liquid Crystal Polymers (LCP's) along with some Metal Matrix Composites (MMC's) and Ceramic Matrix Composites (CMC's). Preliminary investigations have been completed, and most of the LCP's have shown themselves to be unsuitable for storable propellant applications. One LCP, however, has been shown to be compatible with NTO, and it is under consideration for use in further applications. The CMC's and MMC's examined have proven to be more compatible than LCP's, but they are not impervious to the propellants. Testing was not carried out under extreme conditions, (high temperatures, samples under stress), so it does not necessarily indicate how a material will perform under actual turbopump conditions.				
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INTRODUCTION

Program/Task Overview

The Advanced Materials for Turbomachinery (AMT) Program is designed to screen new materials for use in cryogenic propellant (Liquid Hydrogen [LH2] / Liquid Oxygen [LOX]) and storable propellant (Monomethyl Hydrazine [MMH] /Nitrogen Tetroxide [NTO])turbopumps. Replacing metallic parts with advanced materials will decrease the pump weight and increase their service life. Easier manufacturing methods available with some materials will allow a decrease in turbopump cost.

The first consideration for each new material is the ability to withstand the turbopump operating environment. The purpose of this task is to determine how the candidate advanced materials react to the propellant environment. Once a material has been found which can survive in the environment, a part will be fabricated and tested in a turbopump.

Materials Being Tested

The materials used for initial screening tests are various Liquid Crystal Polymers (LCPs). LCPs are injection-moldable plastics that are widely known for their chemical resistance. They were chosen for initial screening due to their ease of manufacturing and high specific strength. LCPs can also be filled with different materials, which allows their mechanical properties to be tailored to specific needs. Examples of fillers include graphite or glass; more information about the LCPs and their fillers can be found in Appendix A.

Tests were also completed on selected Ceramic Matrix Composites (CMCs) and Metal Matrix Composites (MMCs). CMCs are known for their specific strength and chemical resistance. MMCs also have a higher specific strength than non-composite components, and have the same chemical resistance as components. In tests completed to date, two MMCs and three CMCs were exposed to MMH and NTO. More information about the MMCs and CMCs tested can be found in Appendix B.

TESTING METHOD

Testing was designed to determine if any chemical reactions would

take place between the candidate materials and the propellants (MMH and NTO). The following procedure was followed:

1. To remove any moisture trapped within the billets, sample materials were placed into a vacuum oven, heated to 50 degrees Celsius for a period of three hours and then allowed to cool.
2. Samples were weighted and, when possible, measured for size. In some cases, odd sample geometries precluded size measurements.
3. The specimens were immersed in MMH or NTO for 24 hours at room temperature and ambient pressure.
4. After they were removed from the propellants, the samples were oven dried again, reweighed, and remeasured.
5. Several exposed material samples were given an infrared spectroscopy scan to determine what changes took place on the materials surface.

RESULTS

24 Hour Soaks

Most LCPs were not compatible with MMH and NTO. Under the test conditions, any change larger than fractions of a percentage indicated incompatibility. LCPs did show different physical changes due to MMH and NTO exposure. Some of the materials did not change at all, while others, such as HX4000 were almost entirely dissolved away by MMH. Specific results are summarized in Table 1.

The majority of the CMCs and MMCs exposed to the propellants did not change significantly in a 24 hour period. Almost all of the weight changes were on the order of the scale used. See table 2. Also there was no color change in any of the samples.

One Week Soaks

LCPs that proved to hold up better than others in the propellants were exposed for a week to determine if a reaction would take place

Table 1 - Results of 24 hour immersion with MMH and NTO

Material	Wt. Chng in MMH	Wt. Chng in NTO	Dimension Change - NTO	Visible Surface Change - MMH	Visible Surface Change - NTO	Dangerous Byproducts?
Vectra A950	+84%	+05%	IM	None	Lightened	U
Vectra C950	-48	+04	IM	None	None	U
Vectra A625	-3.2	+004	-1.2%	None	None	No
Vectra A130	-16.4	+02	+8	Yellowed	Yellowed	U
Ryton	-.01	+4.4	+4	None	Decomposed	U
HX-4000	-53	+7.56	-3.5	Center Dissolved	Blistered	Yes
Xydar SRT-300	-7.3	-.01	IM	Surface Dissolved	None	No
Xydar RC-210	-20.3	-.02	IM	Surface Dissolved	None	No
Vectra B230	-5.9	+31.3	IM	None	None	No

U = Unmeasured IM = Immeasurable (due to shape) NEG = Negligible

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Table 2 - Results of CMC's and MMC's Exposure to
MMH and NTO for 24 hours

Material Rein/Matrix	Wt. Chng in MMH	Wt. Chng in NTO	Phys Chng in MMH	Phys Chng in NTO
AlO ₂ /Al	0	+ 0.1%	None	None
SiC/Al (billet)	- 0.4%	0	None	None
SiC/Al (sheet)	- 2%	+ 0%	None	None
ZrB ₂ /ZrC ₂ (22% Zr)	0	+ 0.02%	None	None
ZrB ₂ /ZrC ₂ (6% Zr)	0	+ 0.02%	None	None

Table 3 - Results of LCP's one week soak in MMH.
Conditions were ambient

Material	Result
Vectra A625	-22% wt change
HX-4000	-97.7% wt. change
Vectra C950	-11.6% wt. change

Table 4 - Results of LCP's one week soak in NTO under
ambient conditions

Material	Result
Xydar SRT-300	- .1% wt. Change No Change in appearance
Xydar RC-210	- .06% wt. Change No Change in appearance

after extended periods of time. Test results for MMH soaks were not promising, while those in NTO proved to be more encouraging.

A week-long MMH exposure simply caused more of the exposed LCP to be eaten away. The results of the three candidate LCPs that were exposed to MMH for one week are summarized in Table 3.

LCPs exposed to NTO for the 1-week soak held up better than their counterparts did in MMH. Weight losses were on the same order as those of the 24 hour soak, and were small. Test results are summarized in Table 4.

Reasons for Test Stoppage

No more compatibility testing is scheduled between LCPs and storable propellants for the near future. One of the polymers exposed to NTO, HX4000, formed materials on its surface that are similar to some explosives. Since NTO is an oxidizer, this created a possible safety hazard. Any temperature increase of the system during the test could have caused a runaway reaction and explosion.

Any further compatibility testing will be carried out more systematically than in the past. Other facilities, such as NASA's White Sands testing facility, do extensive testing of materials with MMH and NTO, and completely characterize the materials reactions or lack thereof. Research is currently being done into these facilities' methods. The hope is that a merger of the two methods will provide a safe, reliable test that does not require the extensive hardware found at other test areas. When the procedure for the new method is devised, testing will continue at the chemistry lab.

Criteria for Conclusions

A material considered for use in the AMT program must be able to withstand long-term exposure to MMH or NTO in a high-stress environment. The tests carried out in this study involved the material simply sitting in the propellant; there was no simulation of the rotational motion or high propellant flow that an actual turbopump part would be exposed to. Unless some method can be devised of further protecting the materials, any material which lost a significant amount of weight in this test must be removed from consideration for use in higher stress environments.

It is preferable that a candidate material be compatible with both

MMH and NTO. Due to results obtained from the MMH exposures, it was decided to concentrate on determining which LCP would be capable of surviving in an NTO environment. This would allow testing to continue using the LCPs and provide data about their response to the stresses placed upon them by a turbopump.

A material that did not have a major weight loss in the 24 hour period or a major weight gain during the exposure could be considered for short-term use in a storable propellant environment.

CONCLUSIONS

LCP's Overall Suitability

Liquid Crystal Polymers have limited application within turbomachinery. They have an excellent strength-to-weight ratio, but almost all are useless in NTO due to hazardous chemical reactions.

MMH has proven to eat away the polymer itself. In repeated tests, most LCPs have lost much of their weight in a 24 hour soak, and even more mass is lost when exposed for 7 days. Without some form of protection or coating to keep the material away from the fuel, LCPs have no use in an MMH environment.

NTO has mixed effects on the Liquid Crystal Polymers. When some of the plastics were exposed to NTO, they formed potentially explosive compounds, excluding them from further consideration without protection as mentioned previously. Other LCPs seemed to be untouched by the propellant, exhibiting a barely detectable weight change and no significant changes on the surface of the samples.

It is therefore recommended that the use of LCPs in storable turbopumps be extremely limited. Some of the polymers have proven to be able to withstand the NTO environment, and they should be considered for further use in that application. In addition, research should be continued into coatings which would keep the LCPs away from damaging propellants, allowing them to find use in higher stressed NTO environments, or even within MMH.

LCP Recommended for Use in Further Work

The purpose of this task is to quickly determine which, if any, polymers are suitable for further consideration for the AMT program's

storable propellant investigation. In view of the research done to date, the best material for use in a turbopump would be Xydar RC-210. In both day, and week-long NTO soaks, the material lost less than 0.1% of its weight. Caution must be exercised, however, because there is currently no data on the effect NTO has on the strength of the polymer.

CMC's and MMC's Overall Suitability

Overall the five samples of composite materials tested were not affected by the MMH or NTO exposure. Most weight changes measured were close to tolerance on the scale used. Due to this small weight change, it is recommended that CMCs and MMCs be considered for further testing and/or actual application.

Appendix A

LCPs and Fillers

Liquid Crystal Polymers have shown there is use in many engineering applications due to their high strength, chemical resistance, and relatively low density. They also have the ability to be filled with any of several materials to increase some or all of their physical properties. This allows them to be tailored to a specific purpose.

The molecular make-up of the polymers themselves is illustrated in Figure 1. Although the materials are similar, there are differences which account for their varied response to the exposure tests. It is currently theorized that most polymers chains are easily damaged through exposure to MMH and vulnerable to weight gain through exposure to NTO.

The filler within the polymer can be determined by the nomenclature used within it's name. In the case of Vectra materials (Vectra A950, A625, etc) the "A" indicates resin type. The second number in the code indicates the type of filler (in A625, the "6" stands for graphite-flake filling), while the last two digits describe the percentage of the filler (per unit mass). This is not an industry standard; however, other polymer producers vary their designations. The following is a list of the LCPs tested with a description of their fillers:

Materials	Filler/Descr.
Vectra A950	Neat Resin
Vectra C950	Neat Resin
Vectra A625	Graphite Flake Filled
Vectra A130	Glass Filled
Ryton	Neat Resin
HX4000	Neat Resin
Xydar SRT300	Neat Resin
Xydar RC210	Neat Resin
Vectra B230	Graphite Fiber Filled

It has been theorized that some of the fillers actually protect the resins themselves from damage due to propellant exposure. While this mechanism may actually prevent damage in a steady state (such as soaking the material in propellant), it will not help when the plastic is exposed to a propellant flow.

Appendix B

Metal and Ceramic Matrix Composites

Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs) are relatively new engineering materials that are being used more and more in the aerospace industry. They consist of a base material (the matrix) which is then reinforced by fibers or platelets. Usually, the reinforcing material is not the same as the matrix material. This reinforcement increases the specific strength of the material beyond that of its components separately. It also allows for the tailoring of specific mechanical and physical properties (such as heat transfer and thermal expansion coefficient).